Treatment and Placement of Chalk Spoil from the CTRL Thames Tunnel

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Abstract

This paper describes the treatment and placement of chalk spoil from the Channel Tunnel Rail Link (CTRL) Thames Tunnel, a 2.5 km long twin bore tunnel constructed beneath the River Thames using Herrenknect slurry tunnel boring machines. The tunnels pass through variable geology comprising alluvium, terrace gravels and chalk and information is given on each of the material types including their geotechnical properties followed by a description of the treatment methods adopted to process the spoil (screens, hydrocyclones and centrifuges). Special emphasis is given to the treatment of the chalk slurry since this had to be optimised to produce a solid chalk end-product suitable for use as an engineered fill material as part of a landraise development within Craylands Lane Pit , a disused chalk quarry close to the site. Precedent experience gained from other tunnel projects in chalk together with problems previously experienced are briefly illustrated before summarising the results of various trials carried out on site to determine the most suitable method of chalk placement (including windrow trials, spoil treatment trials adding lime and/or cement, compaction trials etc.). A description is given into the methodology and treatment finally selected including the findings to date and any problems met.

1. Introduction

The Channel Tunnel Rail Link (CTRL) is a new 109 km long high speed railway which will run between St Pancras station in Central London and the Channel Tunnel in South East Kent. For the first 30 km, the route runs through East London and Essex along the north bank of the River Thames. The rail link will then pass under the River Thames between Thurrock (in Essex) and Swanscombe (in Kent) in the Thames Tunnel, and continue on south eastwards through Kent to the Channel Tunnel.

The 2.5 km long twin 7.15m internal diameter tunnels under the Thames are being constructed using Herrenknecht mixshield slurry tunnel boring machines (TBM's). These will produce some 263,000 m^3 unbulked spoil material made up of Alluvium (11,000 m^3), Gravel (45,000 m^3) and Chalk (208,000m^3). The original intention was to pump the chalk slurry to a settlement lagoon located on the nearby Broadness Marsh and allow this material to settle and dry out. However, following further appraisals this option was considered to be undesirable. An alternative strategy was therefore developed to use the chalk spoil to regenerate adjacent derelict land by creating a platform for future development. This was also a sustainable and environmentally friendly way to re-use the tunnel spoil. Similar tunnel spoil management methods were adopted at several other locations along the CTRL route, and these were an important aspect of the project's earthworks design.

The chalk tunnel spoil was thus to be deposited in Craylands Lane Pit, a disused chalk quarry located immediately adjacent to the site, see Figure 1. With the end of providing a platform suitable for future development, the contract specification required the chalk tunnel spoil to be treated to attain minimum performance criteria of an undrained shear strength of 50 kPa and a CBR value of 5% within 3 months of final deposition i.e. 2 years after commencement of tunnelling. The majority of the gravels

(occasionally mixed with alluvium or chalk) were to be used in the works as backfill to the approach structures to the bored tunnels. The remaining unsuitable material (typically alluvium) was disposed off-site.

Figure 1 : View northwards of Thames Tunnel including Approach Structures and Craylands Lane Pit

Treating and placing the tunnel spoil as engineered fill in Craylands Lane Pit presented a significant logistical and engineering challenge to the project as it was the first time such a process had been attempted with chalk excavated by a slurry TBM. The system, including the treatment and handling of the spoil, had to be designed to deal with a maximum production rate of 1000 m^3/day. An additional complicating factor was that placement and compaction of the chalk spoil had to be carried out over the wet winter months because there was a lack of available storage space within the pit.

The first tunnel drive started in July 2002 and was completed in March 2003 and the second TBM was launched in April 2003 and is scheduled for completion in December 2003 [1]. The TBM's are expected to achieve an average advance rate of 85 m/week, with a peak production of 150 m/week. This in turn will generate respectively some 4420 m^3 and 7646 m^3 (both unbulked) of tunnel arisings per week, and the spoil management system has to be designed to handle these quantities.

2. Previous Experience from other Tunnels in Chalk

Previous experience of the handling and disposal of chalk arisings has been gained on several tunnelling projects through chalk, most notably the Dartford Road Tunnels, the Channel Tunnel, the Brighton Stormwater Tunnel, the Lille Metro Tunnel, and the Socatop Road Tunnel near Paris which

is currently under construction. A brief description of the experience gained and problems met on each of these projects is summarised below.

Dartford Road Tunnels [2, 3]

These tunnels under the River Thames are about 6 km to the east of the CTRL Thames Tunnel. They are large diameter tunnels (10.3 – 10.7 m cut diameter) which were excavated through Upper Chalk with flints using tunnel shields with compressed air working and ground treatment methods. Spoil disposal for the first tunnel (built in the early 1960's) involved transporting the chalk (and the overlying gravels) from the face via a conveyor to a crushing mill located behind the shield, and then pumping it to the surface where it was discharged into 3m deep settling lagoons. Limited information is available on the geotechnical properties of the chalk spoil but some 105,000 m^3 of chalk spoil was handled in this way and with the exception of 5% of the colloidal material, all the pumped material eventually proved suitable for re-excavation and incorporation into flood protection works.

Channel Tunnel - UK side [4]

On the British side of the Channel Tunnel, Chalk Marl was excavated using open face TBM's (5.4 – 8.7 m cut diameter). The arisings were loaded via a conveyor into 14m^3 side tipping wagons and transported to the Shakespeare Cliff pit bottom. There, these wagons tipped into a bunker storage area from which the spoil was conveyored to the surface and deposited by a radial spreader into a lagoon area located behind a newly constructed seawall. The total volume of cut rock was 3.6 million m^3 with a peak production rate of 10,000 m^3 per day. Minor problems with spoil handling were experienced at the start of the undersea drive for the first 10 kms. These were associated with minor inflows of water present upon excavation which caused the marl to stick to the wagons. Bulking factors from cut chalk to excavated volume and then as placed in the reclamation area were 1.9 and 1.24 respectively. This chalk marl has a much higher clay content than the chalk at the CTRL Thames Tunnel.

Channel Tunnel - French side [4,]

On the French side, Upper, Middle and Lower Chalk was excavated using Earth Pressure Balance (EPB) machines (5.6 – 8.8 m cut diameter). Spoil excavated through a screw was transported in muck wagons to the Sangatte shaft. There the material was crushed (to less than 20 mm in size) and mixed with 50% water in a basculeur, with the resultant slurry being pumped to Fond Pignon reservoir located 2 km distant. Eight twin piston Putzmeister pumps were used, each able to pump 90 m^3/hr of slurry through the 250 mm diameter pipes. The system was designed for 625 m^3/hr of cut chalk with a bulking factor of 1.92. Problems were experienced during construction in slurrifying the spoil and also with blockages in the pipes, which resulted in significant TBM downtime. The spoil disposal system controlled TBM production rates - because it took 45 minutes to process and pump the spoil as against 30 minutes for ring building. On completion of filling, the reservoir held 5.4 million m^3 of spoil representing 3.07 million m^3 of cut chalk. Limited information is available regarding the post-construction properties of the chalk spoil. The grading and the water content of the slurry as pumped changed over time. This reflected the geology encountered, since prior to autumn 1989 a higher percentage of Upper and Middle Chalk and Grey Chalk was encountered in the tunnel but subsequently this was replaced by the more clay-rich Chalk Marl. The slurry produced before October 1989 was more drier and more granular with only 25% smaller than 80 microns, a water content of 25%, and a bulking factor of 1.67 (insitu to placed). After October 1989, the spoil was finer and wetter, with 90% smaller than 80 microns, a water content of 90 – 100% and a bulking factor of 1.8. Recorded settlements of the tailings deposit were greater than 3 m after 2 years and consolidation was expected to continue for 20 years.

Brighton Stormwater Tunnel

This tunnel through Upper Chalk with flints was excavated using an EPB machine (6.9 m cut diameter). The excavated material was loaded into muck wagons, which at the pit bottom were emptied onto a conveyor and taken to the surface to be deposited in holding bunkers. Average production was 100 m^3/day. Handling problems were experienced with the chalk due to high moisture content with chalk sticking to the sides of the muck wagons. These problems were exacerbated by large inflows of water entering the tunnel face plus the addition of water which was needed to wash the muck out of the wagons. Both of these factors significantly wetted up the spoil between the face

and the surface. Flocculants and Eimco filter presses were used to reduce the moisture content of the spoil somewhat. It was then transported by road in sealed tipper lorries to the Sheepcote Valley landfill site 2.5 km distant. The wet chalk spoil at an initial moisture content of more than 30% was placed behind 16m wide bunded areas (1m high bund) and left to dry and re-cement for 8 to 10 weeks in summer and for longer periods during the winter. After this period the spoil was turned over and finally tracked and compacted using a dozer to provide a capping layer to the previous domestic landfill. Tests performed a year later indicated that the moisture content had reduced to 15%. The chalk spoil had also re-cemented with such a substantial strength gain that an excavator bucket was unable to push U100 sampling tube into the ground (estimated CBR value of 25%) and pneumatic drills were required to excavate services trenches.

Lille Metro Tunnel, Northern France[5]

On Contract 4 of the Lille Metro, Upper Chalk with flints was excavated by roadheader. This was as part of the construction of a 1.24 km long twin track railway tunnel, which was 5.8m high and 6.5m wide. The progress rate was 25 m/week. The excavated chalk was broken down and crushed to 50mm size or smaller before water was added to form a slurry. The resultant thick paste was then pumped by Putzmeister sludge pumps up to 600m horizontally along the tunnel and 30m up the shaft into a silo above ground. The capacity of the system was 30 m^3/hr. No problems were reported for this contract but on the adjacent contract, which utilised a mixshield slurry TBM, problems were encountered because 70% of the chalk went into suspension.

Socatop Road Tunnel, Paris, France

Here, Upper Chalk with flints was excavated using an 11.6m diameter Herrenknect mixshield slurry/EPB machine. The chalk had an insitu dry density of 1.56 Mg/m^3, an in situ moisture content of 26%, and a UCS of 2.4 MPa. Excavation of the chalk was carried out in open/EPB mode. Production was 2000 m^3/day. Chalk spoil was transported from the face via a conveyor to barges before being taken along the River Seine to a former sand and gravel pit where it was spread in 0.3 – 1m thick layers across the ground using low ground bearing pressure bulldozers. Problems were experienced with handling the chalk especially during periods of wet weather. These problems included breakdowns of the conveyor leading from the TBM face to the barges due to the sticky nature of the chalk; and problems at the main disposal site where the chalk was initially too wet (porridge consistency) and could not be trafficked nor easily worked. Therefore, as at Brighton the chalk spoil had to be stockpiled over the winter period, but here as a 2m thick layer, before being spread to dry out in thinner layers in the summer months.

3. Trials concerning Thames Tunnel Spoil: Background and Pre-Contract Studies

Importance of Temporary Works Aspects

The temporary works aspects of placing the spoil in Craylands Lane Pit were a particularly important aspect of the trials. Unlike the Dartford, Brighton and Socatop tunnels discussed above, where the spoil was simply lagooned or spread over a very large area, the Thames Tunnel spoil needed to be deposited into Craylands Lane Pit in several layers to an average thickness of about 8m. Significant temporary works issues arose because of the need for several layers of fill and because the total footprint of the quarry available for fill placement was relatively small compared to the spoil production rate: The quarry was about 450m long and 90 - 120m wide – giving a total plan area of about 47,000 m^2. However, the footprint of the conveyor route, buffer stockpile area and access road, and the need to maintain access to a services corridor at one end of the quarry, reduced the plan area during construction available for placement of fill by about 25% to about 36,000 m^2. Assuming an (insitu to compacted) bulking factor of 1.2, a 0.5m layer thickness, and the average programmed tunnel advance rate of 85 m/week (which equated to 4420 m^3 of cut chalk per week) this would require each layer to be overlaid after about 3 - 4 weeks. A key initial goal of the trials was thus that the chalk spoil after placement should gain strength sufficiently quickly to enable it to be trafficked to place the next and subsequent layers. As the contract progressed, an optimised placement method was developed which reduced the severity of this requirement somewhat.

Pre-Contract Studies by Rail Link Engineering
During the design of the scheme and before contract award, Rail Link Engineering (RLE) undertook several studies with the aim of ascertaining the likely properties of chalk spoil from the Thames Tunnels. RLE visited the Sheepcote Valley spoil disposal site in the summer of 1997 to discuss the behaviour of the tunnel spoil with the site manager and also to dig trial pits and recover samples for laboratory testing. T hese provided useful data on the engineering properties of chalk tunnel spoil. In 1999, RLE commissioned Imperial College to undertake some laboratory scale treatment trials on chalk slurry. Again invaluable data was obtained, which was used to prepare the spoil management scheme and contract documents. There is not space in this paper to present the results of these studies, but they will be discussed in detail in a geotechnical paper currently being prepared [6].

4. Trials by Contractor in 2001-2002

The results of RLE's studies (as discussed above) were made available to the tenderers for the Thames Tunnel contract. The contractor continued this process after contract award with a number of trials to predict / confirm how the chalk would behave during excavation using the slurry TBM, transport to the surface, and then during the separation process. Further important trials concerned the treatment of the chalk spoil with lime, cement or other additives. Between contract award and the start of placement of treated spoil in Craylands Lane Pit, the contractor undertook the following trials with the encouragement of RLE: -

- Hydrocyclone trials (May 2001)
- Laboratory spinning trials (June 2001)
- Trials using pilot scale separation plant (April 2002)
- Laboratory Treatment Trials (April to June 2002)
- Treatment trials soon after TBM encountered full face chalk to establish optimum dosage of additive (October 2002)
- Windrowing trials with untreated chalk in Craylands Lane Pit (October 2002)
- Other placement trials in Craylands Lane Pit to optimise placement method (November 2002)

These trials are discussed briefly below. Fuller details are contained in a geotechnical paper [6] which is currently being prepared.

Hydrocyclone and Laboratory Spinning Trials (May/June 2001)
The cyclone and laboratory spinning trials were carried out at Schauenburg's factory (the separation plant manufacturer) at Mulheim in Germany, and at Baker Hughes' laboratory (the centrifuge supplier) in Cologne. The cyclone trials were carried out using one of Schauenburg's 75mm polyurethane hydrocyclones. The feed slurry was produced from chalk sent from the site which was then crushed and ground to smaller than 0.1mm particle size. These trials confirmed that this type of cyclone worked satisfactorily for slurry from the Thames Tunnel chalk over a range of likely inflow densities. They also provided information on the characteristics of the chalk slurry underflow and overflow from the cyclone.
The spinning tests were carried out using the overflow slurry from the cyclone trials with a feed density of 1.16 (9.6% chalk solids by volume and moisture content of about 352%). Tests were carried out spinning a laboratory scale centrifuge at 1000g and 1440g and for between 15 and 60 seconds. No flocculant was added. It is understood that these centrifugal forces and durations represented the range likely to be experienced in the full-size machines, and gave chalk 'paste' moisture contents of between 36% and 52% (densities & dry chalk solid volume of 1.85Mg/m3 & 51% and 1.70Mg/m3 & 41% respectively as compared to in situ chalk of 2.0Mg/m3 & 60% chalk).

Trials at Schauenburg's Factory using a Pilot Scale Separation Plant (April 2002)
In the spring of 2002, prior to starting tunnelling, low density Grade B2/3 chalk from the open cut approach to the tunnel was crushed to a size of 40mm down and delivered to Schauenburg's factory for trials in a 50 m^3/hour pilot scale separation plant, Figure 2. These trials were to provide an estimate of the likely relative proportions and properties (moisture content, grading) of each of the chalk fractions which are discharged from the various screens and hydrocyclones comprising the separation plant, namely:

- chalk (and most of flints) fraction greater than 2.5mm size that is discharged from the coarse screen
- chalk fraction greater than 40 micron size that is discharged from the fine ('dewatering') screen
- chalk fraction less than 40 micron size that is directed to the centrifuges

Figure 2 : Trials at Schaeunberg Factory in Germany using Primary Treatment Plant (screens and hydrocylones) and Chalk from site

Figure 3 : Chalk on fine screen

These trials indicated that only about 30% of the chalk would be discharged from the coarse and fine screens and cyclone underflow (i.e. from the primary separation stage) but that the centrifuges would have to deal with the remaining 70% held in suspension from the cyclone overflow. The trials also indicated that the coarse and fine chalk (coarser than 40 micron) would emerge from the separation plant at a moisture content which would probably not require further treatment, Figure 3.

Laboratory Treatment Trials (April to June 2002)
Initial laboratory treatment trials were carried out on putty chalk recovered from the site.
Further such trials were carried out on the overflow slurry from the pilot scale trials at Schauenburg. Strength gain with time was monitored for samples with initial moisture contents of 30%, 35% and 40% to which various doses of quicklime, cement, or a combination of quicklime were added. These were then compacted using 2.5 kg rammer effort into CBR moulds. The suggested additive dosage resulting from these tests, based on a predicted paste moisture content of 38% and no flocculent addition, was 6% lime plus 4% cement. Subsequent full scale trial panels when tunnelling reached full face chalk showed that a much smaller dosage was required, as discussed below.

Trial Panels
0.25m and 0.5m thick trial panels were undertaken on site during the early stages of tunnelling, in warm autumn weather, Figure 4. These were to determine the dosage of cement and/or lime required to give the specified undrained shear strength of 50 kPa and 5% CBR value within the stated time period using the methods of working and placement as then proposed within Craylands Lane Pit, Figure 5. Nine panels were constructed using the chalk spoil discharged from the separation plant and centrifuges with various combinations of lime and cement. Full details of these trials will be published in a separate geotechnical paper, however the results were briefly as follows: -

- The panels treated with lime showed a short term strength gain as a result of the exothermic effect of the quicklime but no further long term strength gain.

- The panels treated with lime plus cement rapidly produced high strengths, but at high additive dosages.
- The panels treated only with cement gained strength more slowly, but were at much lower (and thus more economic) dosages.

Figure 4 : Chalk Placement and Compaction in Panels

Figure 5 : CBR Testing

Figure 6 illustrates some of the results obtained from the trials. The trials indicated that the addition of 3% cement to the paste when mixed with the coarse/fine fraction discharged from the screens was likely to give the strength required. The beneficial mixing of the paste and the coarser fractions plus the flocculent added to the slurry in the centrifuges (which increased the Liquid Limit of the paste by about 3% to 36%) both combined to reduce significantly the amount of additive required compared to the dosage predicted from the laboratory trials.

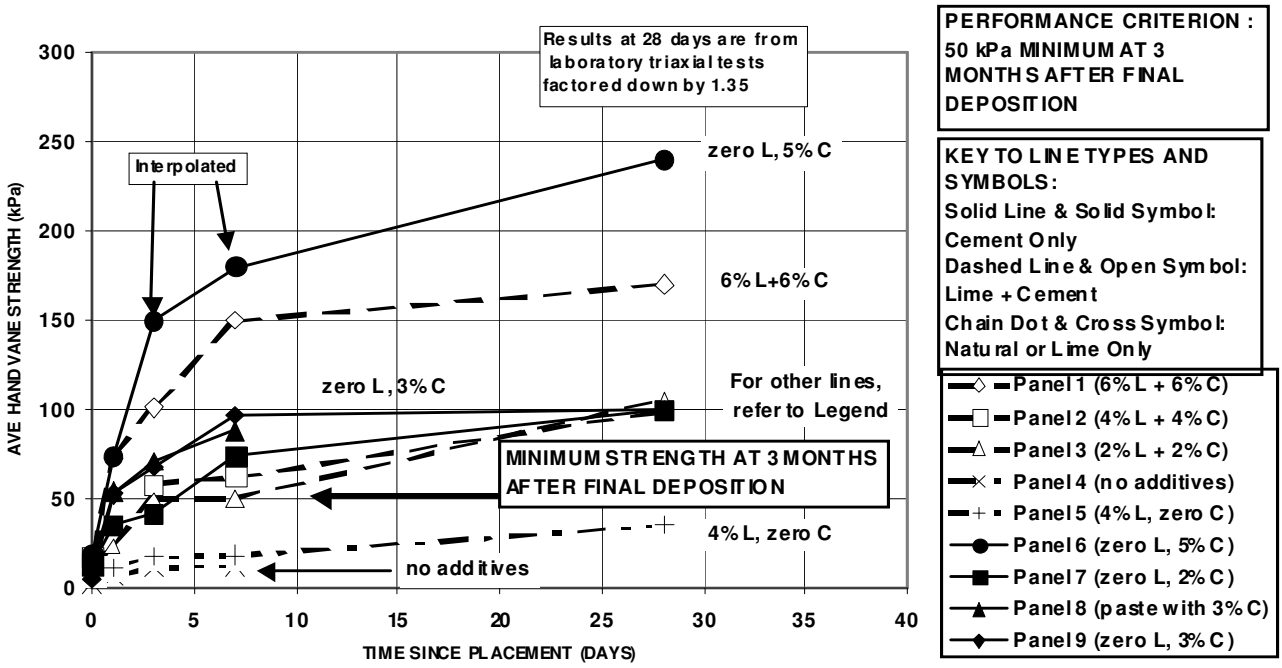

Figure 6 : Results of Treatment Trials

Windrowing Trials in Craylands Lane Pit
Windrowing trials, which consisted of turning over untreated chalk tunnel spoil each day to dry it out, were undertaken in Craylands Lane Pit. After 3 days the material was starting to gain some strength, but it was concluded that there was simply not enough space in the quarry for this method and that it was too plant intensive.

5. Separation and Treatment Process

During the excavation cycle the chalk at the face containing up to 15 - 20% flint is broken down from its natural state by operation of the Herrenknecht mixshield TBM. A jaw crusher and grillage arrangement installed at the front end of the machine ensures that no chalk or flints above a size of 150mm enters the 350mm diameter slurry pipeline. Due to the particle size of the chalk itself, material in the size range 150mm down to 0.002mm has to be handled. The slurry from the face is then pumped to the surface to a treatment plant (Figure 7) where a series of screens and hydrocyclones (primary stage separation) and centrifuges (secondary stage separation) remove the solid component of the slurry (Figure 8). Excess wastewater from the process is passed through a series of settlement tanks where additional water (taken from the groundwater dewatering of the approach structures) is added before being discharged to the River Thames. All of the spoil is sent via conveyor to Craylands Lane Pit. A simple flow diagram of the complete separation process is included as Figure 9.

Figure 7 : Treatment Plant

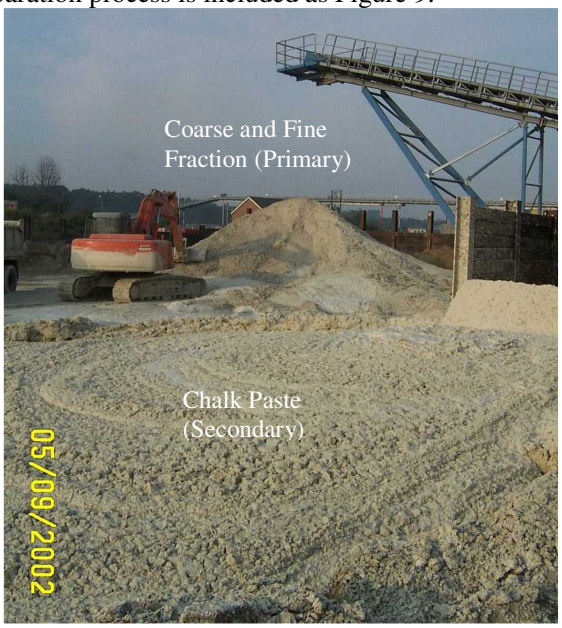

Figure 8 : Treatment Products

Primary Separation Plant
The *primary separation plant* is modular in form and is made up four identical parallel inline units linked to a large combined underflow tank in the base of the plant. The plant is rated to process 1800 m3/hour of slurry which equates to about 450 tonnes/hour of solid material. Each unit carries out a multi-stage separation process with partial dewatering of the fines sludge using hydrocyclone separation. The first stage removes the coarse component of the spoil using a series of bar sizers and screens down to a particle size of 2.5mm. Most of the flint together with lumps of in situ chalk, with an average moisture content of 25%, is removed at this stage and directly discharged via a chute to the main disposal conveyor. The remaining underflow from the 2.5mm screen is then circulated through a

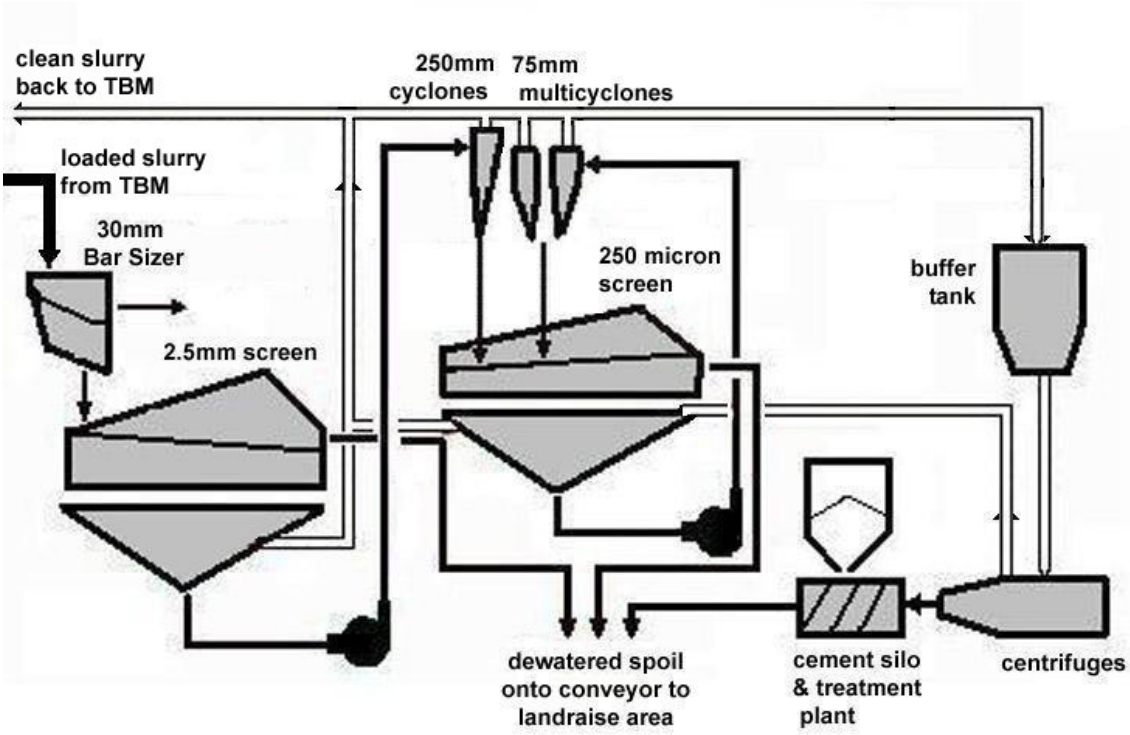

Figure 9 : Treatment Process - Flow Diagram

This material content, with an average moisture content of 28%, is also discharged onto the main disposal conveyor. Any underflow (average moisture content 80%) passing through the dewatering screen is recirculated back into the hydrocyclone system to ensure complete removal of the chalk material above 0.04mm size.

Secondary Separation Plant

The overflow from the 75mm multicyclone stage is fed directly back into the slurry circuit. The slurry is then sent back to the face (optimum slurry density between 1.1 – 1.3 kg/litre). However, when the slurry density exceeds 1.3 kg/litre, the slurry is diverted to the centrifuges where a flocculent (Superfloc A100PWG) is added to the creamy liquid (dosage rate 50ppm per 0.05% solution) before it is spun to produce a chalk 'paste' solid component, with the excess water being sent to a settlement tank. The flocculated chalk paste typically has a moisture content in the range 40 - 50% (average 44%) and has a "porridge" consistency. As discussed above, in the section on the trials, natural chalk without flocculent but with a similar moisture content would have the consistency of "single cream". Hence the flocculent appears to have aided the separation process by causing the silt-sized particles to aggregate whilst raising the liquid limit of the chalk material itself and thus making it appear drier.

Cement Addition

The chalk paste is discharged via a small conveyor into a screw feeder mixing drum. There, cement from a silo is added and mixed in with the paste to accelerate the strength gain. The amount of cement added is varied according to: -

- the weather conditions
- the strength gain measured over a 24 hour period
- information on the workability of the chalk material during placement in the pit itself.

Typically 3 – 4% cement is added such that after 24 hours an early strength of 22 kPa is achieved. This is the strength deemed suitable to allow the material to be handled immediately and placed in Craylands Lane Pit. This has been increased to 5 – 6% during periods of exceptionally wet weather in order to increase the early strength to 40 kPa and to mitigate problems associated with trafficking and placement. The early 24-hour strength gain is measured three times per day and dosage rates adjusted to suit. The treated paste is then also discharged onto the main disposal conveyor along with the coarse and fine fractions being discharged from the primary separation plant and the total chalk spoil is transported to Craylands Lane Pit.

6. Transport of Spoil to Craylands Lane Pit

As a result of a number of changes in direction between the separation plant and the discharge point, there are five main conveyor belts en route to the pit. The conveyor system almost 1km in length is covered throughout its full length. Where it crosses watercourses a solid floor with edge upstands is fixed to the underside of the support structure to prevent any spillage of chalk and consequent pollution. An emergency stop cord runs along both sides of the conveyor. The final conveyor is inclined to provide enough height to allow stockpile room underneath for up to 4 days' production. The entire system is controlled via a panel located in the separation plant. This panel allows the operator to start the belts manually or via the auto start function which will start the belts in reverse order (i.e. 5, 4, 3, 2 and 1). Prior to moving the belt there will be an audible and visual alarm. The operator also has a television screen with video links to critical points along the conveyor system - in particular transfer stations between the five belts.

7. Plant Modifications undertaken during Construction

Secondary Separation Plant

Initially the secondary separation plant was equipped with three centrifuges with a total input slurry capacity of 210 m^3/hr producing 48 tonnes/hr of solids. During the early stages of the down-line tunnel drive, it became evident from the nature and quantity of the chalk slurry to be processed, that additional capacity of the secondary system would be required. A decision was made to install an additional three centrifuges bringing the slurry capacity up to 470 m3/hr with an output of approximately 100 tonnes/hr solids. With these additional centrifuges on line the TBM productivity reached over 130 m/week and peaked at 18 rings per day i.e. 27m / day. The separation plant, centrifuges and flocculent system are maintained and operated by five operatives. Combined downtime of the slurry system and separation plant has reduced from 40% at the start of the first drive to 27% towards the end and hopefully will be further reduced for the second drive.

Cement Mixing Plant

The system was originally set-up with a single in-line cement mixing plant to dose the chalk paste. The screw in the mixing drum often became clogged and maintenance could only be carried out with the mixing plant out of commission. To remove this restriction, an additional mixing unit (with feed conveyors) was installed over the Christmas 2002 shutdown period and this has proved successful in reducing the downtime.

Conveyor System

Breakdowns to the conveyor system leading to Craylands Lane Pit still occur from time to time. When this happens, or if a problem occurs with the cement dosing plant, then the material discharged from the separation plant and centrifuges is diverted to a temporary stockpile area with a capacity of 3000 m^3) immediately adjacent to the plant. Once the problem is repaired, this material is then transferred back onto the conveyor utilising a mobile hopper and chain conveyor or loaded onto a lorry for off-site disposal or use in the works. Problems with the conveying system generally result from clogging of the belt scrapers. At times this has caused overload of the power transmission system (damage to motors) or physical damage to the belt. The conveyor system is maintained by two full time operatives who continuously clean and maintain the belt.

8. Placement of Chalk Spoil within Craylands Lane Pit

Chalk and flint spoil comprising the combined coarse and fine fractions (typically 40% of the material with a moisture content of 22 – 32%) together with the treated chalk paste (typically 60% of the material with a moisture content of 40 – 48% before treatment) falls from the conveyor into a temporary stockpile area within Craylands Lane Pit (see Figures 10, 11 and 12). From here tracked excavators immediately load 25 tonne capacity articulated dump trucks and these transfer and tip the material onto the pit floor immediately adjacent to the area where it is to be placed. The dump trucks do not traffic over previously placed spoil. Low ground pressure long reach excavators then place and compact the material into 1m thick layers such that a series of benches is progressively built up, Figure 13. Early trials indicated that placement and "tamping" by the excavator bucket of the "fresh" spoil material produced a reasonable strength gain with time as the cement in the treated paste started to take effect. The air voids content in the compacted layer is typically 5%. Secondary re-handling and reworking of the spoil after placement were detrimental to both the strength and compaction achieved and thus had to be avoided. It was therefore essential that the excavators had sufficient reach to enable freshly produced spoil to be collected from the pit floor and placed in its final position in the same working day. For the higher benches, two long reach excavators were required to achieve this. Each layer is placed with falls sufficient to shed rainwater quickly – i.e. not less than 1Vert:50Horiz.

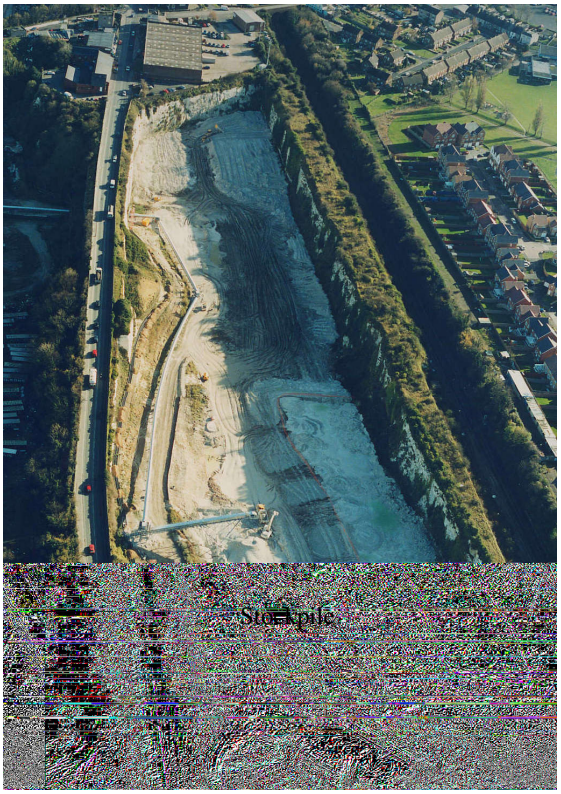

Figure 10 : Craylands Lane Pit - view east

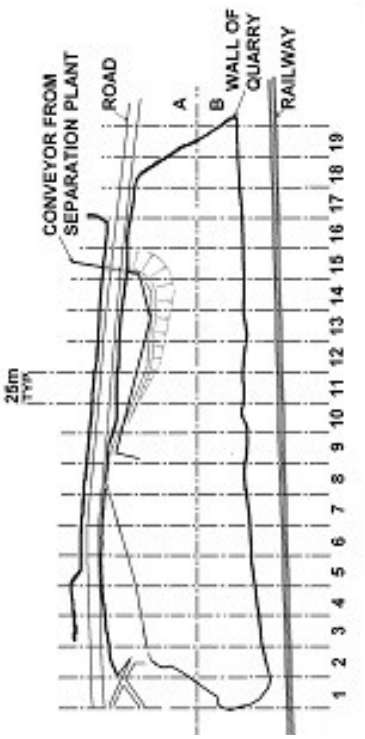

Figure 11 : Plan of Cells

The width and height of each bench generally do not exceed 7m and sideslopes are 1V:2H. Because of the soft condition of the "fresh" chalk spoil, the long reach excavators sit on 5m wide mats to reduce further their ground bearing pressure and minimise the risk of "bogging" in the fill. The progression of the fill face is generally from east to west across the full width of the pit. For management and monitoring purposes, the quarry is divided by survey markers into 38 cells (A or B, 1 –19), each about 25m wide and between 30 – 50m in length, Figure 11. Also, levels (in metres above Ordnance Datum) are painted on the chalk walls of the pit, to guide the filling operations. This allows good control of : -

- material placement, including date and depth of placed layers, and nature of material placed

- subsequent testing such as strength gain over time
- monitoring of possible concerns such as chalk wall instability

Prior to filling against the sides of the pit, the vegetation growing on the chalk walls is removed and disposed offsite.

Figure 12 : Coarse/fine chalk fraction and cement stabilised chalk paste falling from conveyor into stockpile where it is loaded into Moxy lorries to be transported to placement area.

Figure 13 : Placement of Chalk

Placement of chalk spoil is undertaken throughout the year including over the winter season and during rainy periods. Only when the weather is extremely wet do the placement operations cease and the chalk is stockpiled as necessary. As discussed above, due to the size of the pit and other factors, not all of the chalk tunnel spoil can be placed and compacted straight into its final location. Therefore about 68000 m^3 will need to be temporarily stockpiled and only placed in its final position once the conveyor and associated equipment is removed. Prior to commencement of the works within Craylands Lane Pit, several boreholes were drilled deep into the chalk beneath and immediately adjacent to the site to establish the hydrogeological conditions. Regular monitoring of both water levels and water chemistry (in particular chloride levels) are undertaken to ensure no detrimental changes occur associated with the spoil placement and landraise activity.

9. Performance of Fill Six Months after Start of Placement

Regular testing of the compacted spoil has been carried out in each cell throughout the construction phase. The following tests have included :

- Daily to weekly determination of the moisture content and undrained hand vane shear strength. Tests performed at surface at various locations and levels within each cell. Figure 14 illustrates the results obtained for one typical cell location.

- Determination of the moisture content, undrained strength (hand vane strength and triaxial strength) and percentage air voids with depth. Various tests are performed on U100 samples taken at surface and from trial pits excavated in the fill and from boreholes drilled at several locations at the site.

The information obtained to date (six months after start of placement) indicates that the placed chalk spoil has a bulk density of 1.8 Mg/m^3 as compared to 2.0 Mg/m^3 for the in situ chalk and has a air voids typically between 4 – 7% (range 0 – 10%). The low air voids reflects the "wet" nature and fine grading of the spoil material when placed. Strength measured to date are on average generally above 50 kPa on average and these are likely to increase as the chalk re-cements and loses further moisture. This is highlighted by the fact that at the time of placement, one could not walk across the spoil without sinking in to the knees but six months later articulated dump trucks are able to run over the surface with little difficulty. Estimates of the volume placed to as dug chalk for the first tunnel drive would indicate a bulking factor from in situ chalk to as placed chalk fill to be about 1.1.

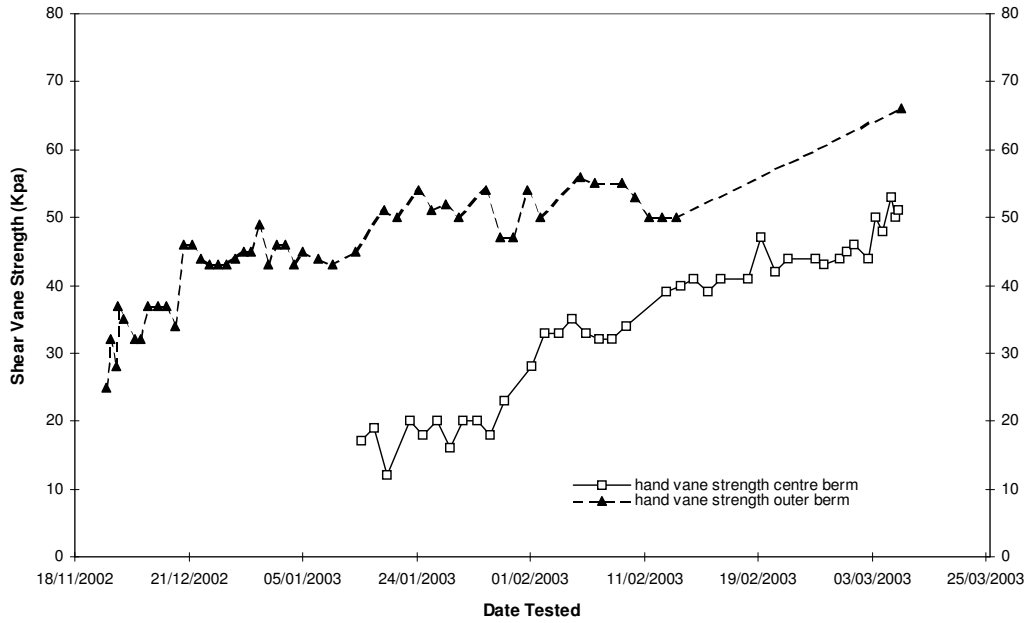

Figure 14 : Hand Vane Strength for Cell A16

10. Conclusions

The successful and sustainable re-use of the chalk tunnel spoil from the CTRL Thames Tunnel for engineered fill was the result of several years of pre-contract geotechnical investigations and studies, careful plant design, and extensive trials between contract award and the start of tunnelling. Although some early difficulties were experienced in dealing with the chalk slurry and placing the material within Craylands Lane Pit, these were soon overcome through engineering ingenuity aided by co-operative working between all parties. Generally in chalk earthworks, one tries to reduce breakdown of the chalk lumps, adding water, and working the chalk over the winter – however the Thames Tunnel team had to do all three to produce a satisfactory platform for future development.

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